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Sea Ice - Atmosphere Interaction

Application of Multispectral Satellite Data in Polar Surface Energy Flux Estimates

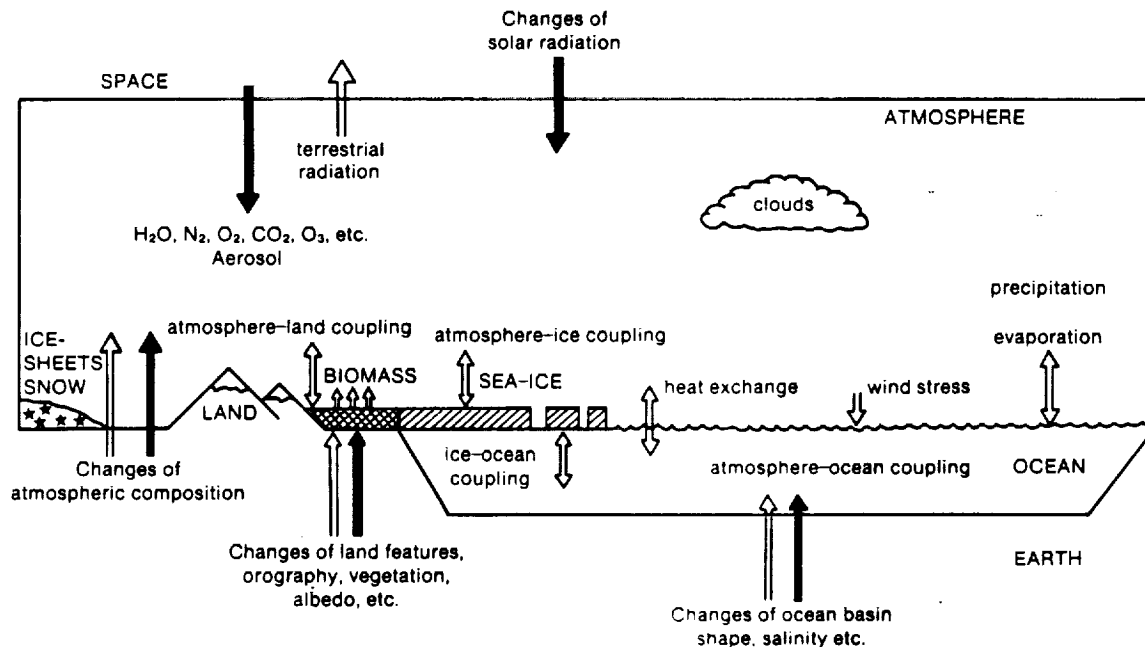
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1. Introduction

R. Weaver

The following report briefly outlines our progress under the Sea Ice - Atmosphere Interaction: Application of Multispectral Satellite Data in Polar Surface Energy Flux Estimates, proposal NAGW-2158. In the past six months we have continued our work on energy flux sensitivity studies, ice surface temperature retrievals, corrections to AVHRR thermal infrared data, modelling of cloud fraction retrievals, and radiation climatologies. Each of these topics are presented in the following sections. It must be noted that these reports represent work in progress. A more complete report will be presented in the next annual report and in the various research papers either in press or in preparation.

Summary

We tentatively conclude that the SSM/I may not provide accurate enough estimates of ice concentration and type to improve our shorter term energy flux estimates. SSM/I derived parameters may still be applicable in longer term climatological flux characterizations. We hold promise for a system coupling observations to a ice deformation model. Such a model may provide information on ice distribution which can be used in energy flux calculations.

We have found considerable variation in modelled energy flux estimates when bulk transfer coefficients are modulated by lead fetch. It is still unclear what the optimum formulation is and this will be the subject of further work.

Data sets for ice surface temperature retrievals have been assembled and preliminary data analysis has started. More data will be collected this coming summer over Greenland and possibly over the central Arctic from a Soviet Ice Breaker, if funding is approved.

Finally we have started to construct a conceptual framework for further modelling of the Arctic radiation flux climatology.

END

2. Sensitivity of Passive Microwave Data for Heat Flux Retrieval

A. Schweiger and K. Steffen

The potential of passive microwave derived sea ice information for the calculation of heat fluxes at the Arctic ocean surface was investigated. The sensitivity of individual surface energy balance terms to the information content and the inherent error in the passive microwave derived sea ice parameters was tested using a simple energy balance model of the ice covered ocean surface. The model follows Maykut (1978) with a modification to allow for variable lead sizes and is discussed in a previous report (Steffen et al., 1990). Ice thickness distributions from dynamic ice modelling experiments (Maykut, 1982), as well as climatological data on radiative components were utilized to compute turbulent fluxes over sea ice. Calculations were made using the full (Maykut type model) thickness distribution in 5 categories, a 2 category thickness distribution (ice/open water) optimized for passive microwave data, and a 3 category thickness distribution (thick ice/thin-ice/open-water) using a passive microwave algorithm assuming a limited thickness (< 0.8 m) of the first-year ice category. Some of the preliminary results are summarized below and will be detailed in a later report.

2.1 Marginal Ice Zone

In the marginal ice zone, where thin ice types dominate, information on the relative abundance of these ice types is necessary to compute turbulent fluxes with any reasonable accuracy. Current passive microwave algorithms, are not capable of producing this type of information. Even though individual studies (Steffen, 1991) have shown that the different emissivity of thin ice indicates a potential for the retrieval, this capability is limited to situations when the extent of thin ice types is large enough to cover an entire footprint. Further work, through a combination of different sensors, eg. AVHRR ice surface temperatures or inclusion of coupled dynamic/thermodynamic ice models might improve this situation.

2.2 Central Pack Ice

In the central pack, the use of ice concentrations, in the calculation of the turbulent part of the energy balance faces different set of problems. If one assumes, that ice concentrations may be retrieved with 100 % accuracy by a particular passive microwave based sea ice concentration algorithm, then the potential error due to poor thickness resolution (2 category algorithm, open water/ice) is of the same order of magnitude as the variability that can be expected to be observed (Fig. 1). This fact eliminates the capability to monitor any changes in the surface energy balance due to changes in ice concentrations over time. The inclusion of passive microwave observed ice concentrations will not significantly improve estimates of surface energy balance calculated solely from other data. While a hypothetical 3 thickness category algorithm (0.0-0.1m, 0.1-0.8 m, > 0.8 m) would

significantly reduce the above discussed problems (see Fig. 2 compared to Fig. 1), the following questions need to be answered:

In what way do variations in the observed passive microwave signal and derived geophysical parameters (ice types: open water, first-year ice, multi-year ice) relate to energy balance calculations (turbulent component).

If one assumes that first year ice grows to a certain thickness (up to 0.8 m), then flux calculations would be relatively straight forward assuming a linear temperature gradient in the ice. Fluxes over the thick multi-year ice could be estimated using a multi-level thermodynamic model (eg. Semtner, 1976). Certain assumptions would also have to be made regarding how the model the characteristics of the ice surface due to ice movements. We are considering alternatives as to how one might model ice floes that are moving through regions of differing energy balance conditions (eg. ice flows from the marginal pack, through the central Arctic or vice versa).

Unfortunately, the assumption of FYI representing a category of particular ice thickness is not a very good one, since thin ice is constantly undergoing dynamic deformation. Thermodynamic profiles of deformed FYI are most likely similar to those of MYI, and can therefore not be approximated using the linear gradient model (unpublished data Resolute Bay, K. Steffen). Due to this fact, a passive microwave based algorithm would have to produce information on open water fraction, undeformed FYI ice and deformed ice. There is some indication that deformed FYI ice signatures are similar to those of MYI because of brine drainage, and greater amounts of snow, but evidence for this fact is sketchy and can hardly be accepted in a general sense.

In light of the above outlined problems, the question as to what can be done in terms of their resolution has to be discussed. Accepting the fact that only 2 thermodynamically relevant classes can be retrieved using passive microwave sensors, assumptions regarding the distribution of thinner ice types must be made. The simplest approximation is to assume constant relationship between the classes. This is probably not a very good assumption, since the presence of open water and thin ice are interconnected. Since thin ice is formed in developing leads especially in years with greater dynamic activity, the fraction of open water would be expected to be larger and, therefore, result in the production of greater amounts of thin ice. On the other hand, a greater dynamic activity would also cause increased ridging of thin ice which would offset the increased production of thick ice. With respect to compiling a climatology of fluxes, a constant or seasonally varying distribution would be difficult to justify. The question is then: what is the "correct" climatological distribution of thin ice. Data from Arctic submarine sonar are limited to summer (Queenfish, Nautilus) and spring (Gurnard) and provide information over very limited areas. They contribute little to our description of surface variability for a surface energy balance climatology. Maykut (1978, 1982) computed a spatially invariant surface energy balance for the central Arctic which employed modelled ice thickness distributions derived from a thermodynamic/dynamic model. These modelled ice thicknesses can then be used in the calculation of the surface energy balance.

Maykut's ice thickness distributions are based on strain data from Arctic ice islands and are limited to an area in the Beaufort Sea. For the computation of a basin wide surface energy balance climatology, thickness distributions are required for the entire basin. Hibler and Flato have implemented the ice thickness distribution theory developed by Thorndike et. al (1975) in their large scale sea ice model. Thickness distributions from this model would represent a suitable data set for the task at hand. Turbulent exchange at the ice/atmosphere interface could be calculated using this distribution using a multi-level thermodynamic model (eg. Semtner 3 layer model). The use of modelled ice thickness distributions is somewhat circular though: Since dynamic/thermodynamic sea ice models calculate ice growth based on computed fluxes, these model calculations should provide the desired climatology directly. But this is not quite so. Since the thermodynamic calculations in Hibler's model are based on the 0 layer SEMTNER model, the temperature gradient for all ice types is assumed to be linear. While this assumption produces ice growth rates that are in reasonable agreement with the multi-layer calculation, the energy exchange at the surface is modelled inaccurately. As indicated in Fig. 3, the large scale area weighted fluxes can be quite different and even reversed in direction, when a linear temperature gradient assumption is made. While modelers realize this inconsistency, the formulation of more realistic thermodynamics (e.g. a multi-level model) poses significant difficulties in terms of modelling the advection of the vertical ice temperature gradient (Hibler pers. communication). In light of the fact, that ice thickness distributions may be considered relatively accurate with respect to the problem at hand, the proposed "circular" approach seems to have validity.

If ice thickness distributions can be modelled though, the use of passive microwave information in the calculation of the Arctic surface energy balance assumes a different role. This role would be the validation of and accuracy assessment of the modelled ice concentrations. If modelled ice concentrations match passive microwave derived concentrations, the argument may be made, that the ice thickness redistribution function reflects the physical processes involved in converting the various ice thicknesses is also correct. An important step in the compilation of a ice thickness climatology would therefore be the cross-validation of modelled and passive microwave derived ice concentration. This comparison would further provide some limits on the errors that can be expected in the calculation of the surface energy balance based on modelled ice thickness distributions.

In the previous discussion we made the assumption, that ice concentrations can be retrieved with absolute accuracy by the a passive microwave based algorithm. This of course is not so. We have found in previous studies, that the error in ice concentrations lies in the order of 3 % (Steffen and Schweiger, 1991). The selection of appropriate tie points, for particular areas and times of the year though might distribute the error evenly about the mean, so that for longer term averages the assumption of an accurate open water fraction might not be such a bad one.

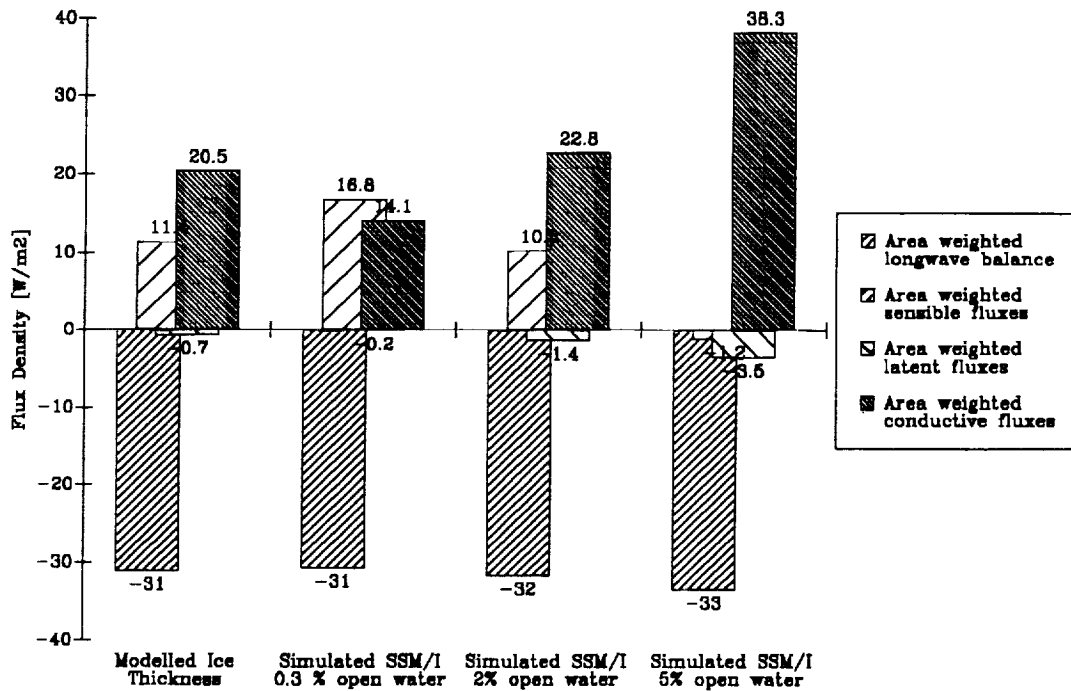


Fig. 1: Central Arctic energy balance in January calculated from a number of different ice thickness distribution categories.

Category 1, (modelled ice thickness) represents the energy balance as calculated for the full thickness distribution derived from dynamic/thermodynamic model calculations.

Category 2 (simulated SSM/I 0.3 %) represents the energy balance calculated based on a simulated SSM/I algorithm. SSM/I ice concentrations were simulated by summing ice thicknesses > 0.05 m in the modelled ice thickness distribution.

Category 3 represents the energy balance in January when 2 % open water would be present, corresponding to the observable natural variability.

Category 4 assumes 5 % open water which would have to be considered an extreme case.

Note that the difference between category 1 and 2 is caused by the reduced resolution in ice thickness estimate as derived from SSM/I data. This uncertainty is of the same order of magnitude as the expected variability.

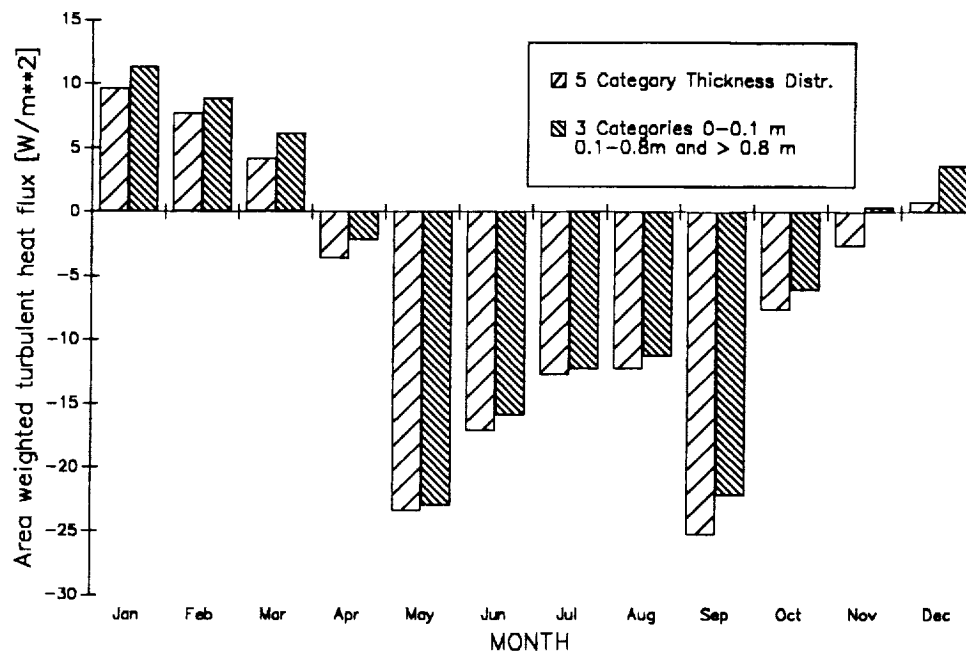


Fig. 2: Turbulent heat fluxes [Wm^{-2}] calculated for a 5 category (0-0.1, 0.2, 0.4, 0.8, > 0.8m) and 3 category (0-0.1, 0.8, > 0.8 m) thickness distribution.

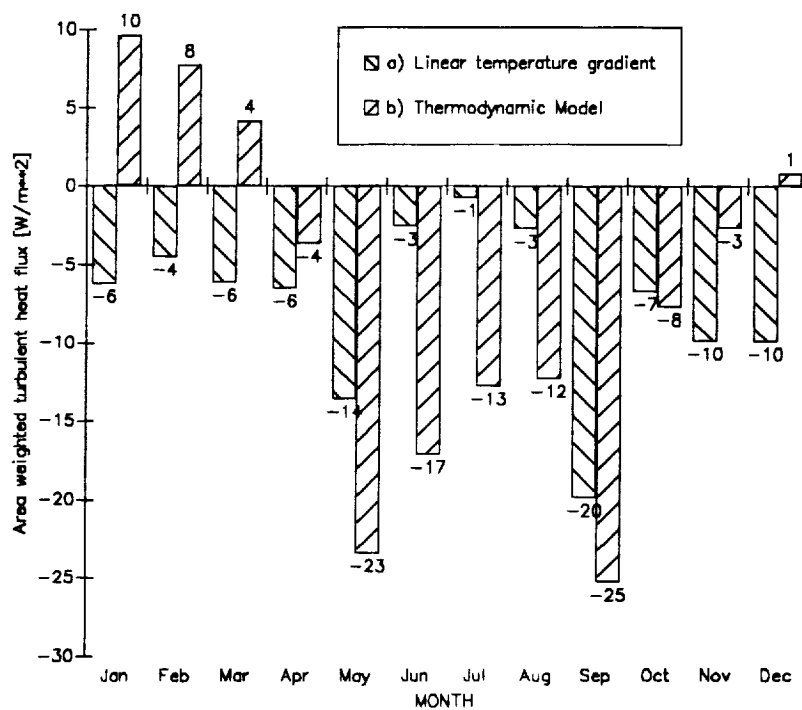


Fig. 3: Area weighted turbulent flux densities [Wm^{-2}] for the Beaufort Sea area, assuming a) a linear temperature gradient for thick ice (3 m) and b) from a multi-layer thermodynamic model. Note that during the winter months fluxes have opposite direction. Negative values indicate fluxes away from the surface.

3. Sensitivity of Large-Scale Heat Flux Estimates to Lead Width

J. Maslanik and J. Key

A formulation to adjust turbulent-flux bulk transfer coefficients that takes atmospheric stability and fetch into account was combined with a one-dimensional ice growth model, meteorological observations, and ice thickness data to calculate the sensitivity of turbulent fluxes to changes in fetch, wind speed, air temperature, and surface temperature in the Arctic. The importance of fetch under actual lead width distributions, concentration, and ice thickness conditions is estimated using submarine sonar observations. The fetch sensitivity increases with decreasing wind speed and with increasing instability. For high wind speeds, fetch dependency is minimal for ice thicker than about 0.10 m. At a fetch of 10 m, the use of adjusted transfer coefficients rather than a fixed value of 0.003 results in a decrease in sensible heat flux of 7 % for open water, 9 % for 0.15 m ice, and 11 % for 0.30 m ice, using meteorological conditions typical of January in the western Arctic (Fig.4). At a thickness of 0.05 m, averaged fluxes for November through March calculated using the fixed transfer coefficient are 8 % greater than fluxes calculated with a fetch of 10 m, 22 % greater than fluxes estimated with a 50 m fetch, and 29 % greater than fluxes for a 100 m fetch. Calculations of equilibrium ice thickness using an ice growth model forced by turbulent fluxes estimated with and without fetch and stability adjustments yields a 2 % decrease in annual ice thickness if a mean fetch of 10 m is used, and a 23 % decrease if a mean fetch of 100 m is assumed compared to ice thicknesses estimated using a fixed coefficient of 0.003 for sensible and latent heat flux. In comparison, an increase in wind speed from 5 ms^{-1} to 6 ms^{-1} at a 10 m mean fetch increases the mean annual ice thickness by 9.9 %, while a 10 % increase in cloud cover decreases the annual thickness by 14 %. Using an observed distribution of ice thicknesses and lead widths, sensible fluxes from the lead ensemble are reduced by 42 % when a fixed coefficient is used. Substituting these fluxes from open and refrozen leads for the open-water flux in the ice thickness model increases annual mean ice thickness by 9 % when adjusted coefficients are used.

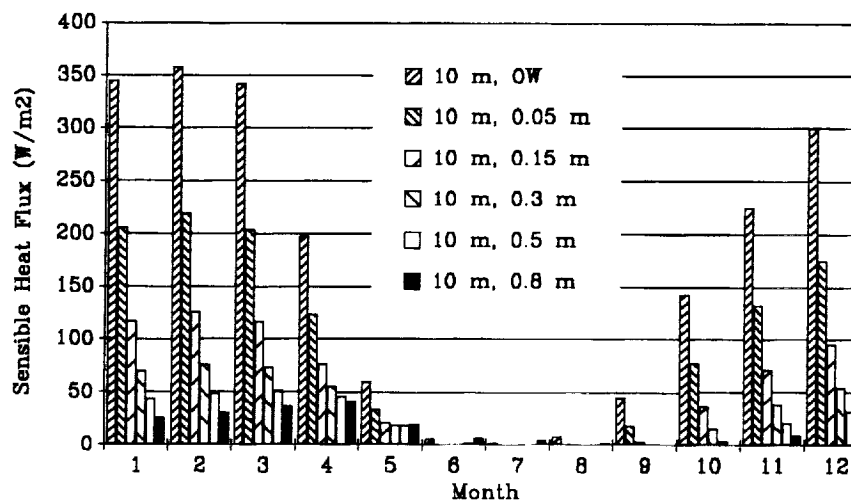


Fig. 4: Mean monthly sensible heat transfer from a 10 m lead of different ice thicknesses. Forcing: Buoy data for the central Canada basin, 1979-1984.

4. Calibration of AVHRR-TIR Sensor

K. Steffen and M. Haeffliger

The surface temperature derived from AVHRR thermal infrared sensor (TIR) will be inter-compared with outputs derived from the transmission model LOWTRAN-7 and in situ measurements from the 1990 ETH expedition camp on the Greenland ice sheet. The surface temperatures were measured with thermistore profile chains, and in addition the complete radiation balance was obtained at the same site. Radiosonde profile measurements from the expedition camp (Fig. 5), obtained on a daily basis, are used as input data for LOWTRAN-7, which can provide a good validation data set for the AVHRR SST retrievals. The in situ ground measurements also provide a means of calibrating the LOWTRAN-7 atmospheric model simulations. Data analysis has been completed and we have ordered AVHRR images for case studies the 1990 observation period.

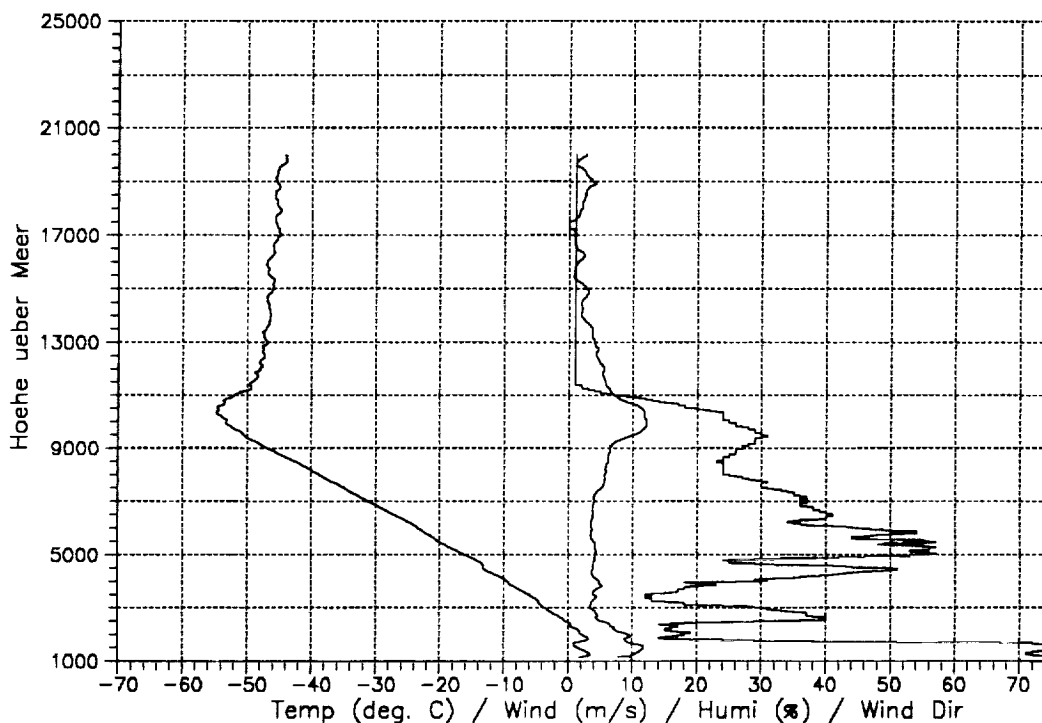


Fig. 5: Radiosonde profile measurement at the Swiss expedition camp on the Greenland ice sheet, June 17, 1990.

5. Ice Surface Temperature Retrieval

J. Key, M. Haeffliger)

Work on the retrieval of ice surface temperature from the AVHRR thermal channels is continuing. In situ rawinsonde and ground-based cloud observations from Soviet ice islands have been processed and statistically grouped into three temperature and humidity clear sky "seasons" (Fig. 6, 7). The daily data are then used in radiative transfer calculations of the simulated AVHRR measurements, taking into account the response functions of the NOAA-7 and 11 AVHRRs. Since the actual surface temperature is unknown (the first measurement is generally the shelter temperature at approximately 1.5 m), an energy balance model is used to estimate a reasonable range of surface temperatures based on the observed wind conditions. Atmospheric correction coefficients will then be derived through a multiple regression procedure for various combinations of channels, and for scan angle dependencies. An overview of this material was presented at the WMO-sponsored workshop "Polar Radiation Fluxes and Sea Ice Modeling" held in Bremerhaven, Germany, 5-8 November 1990. A paper providing the detailed results of this work is currently in preparation.

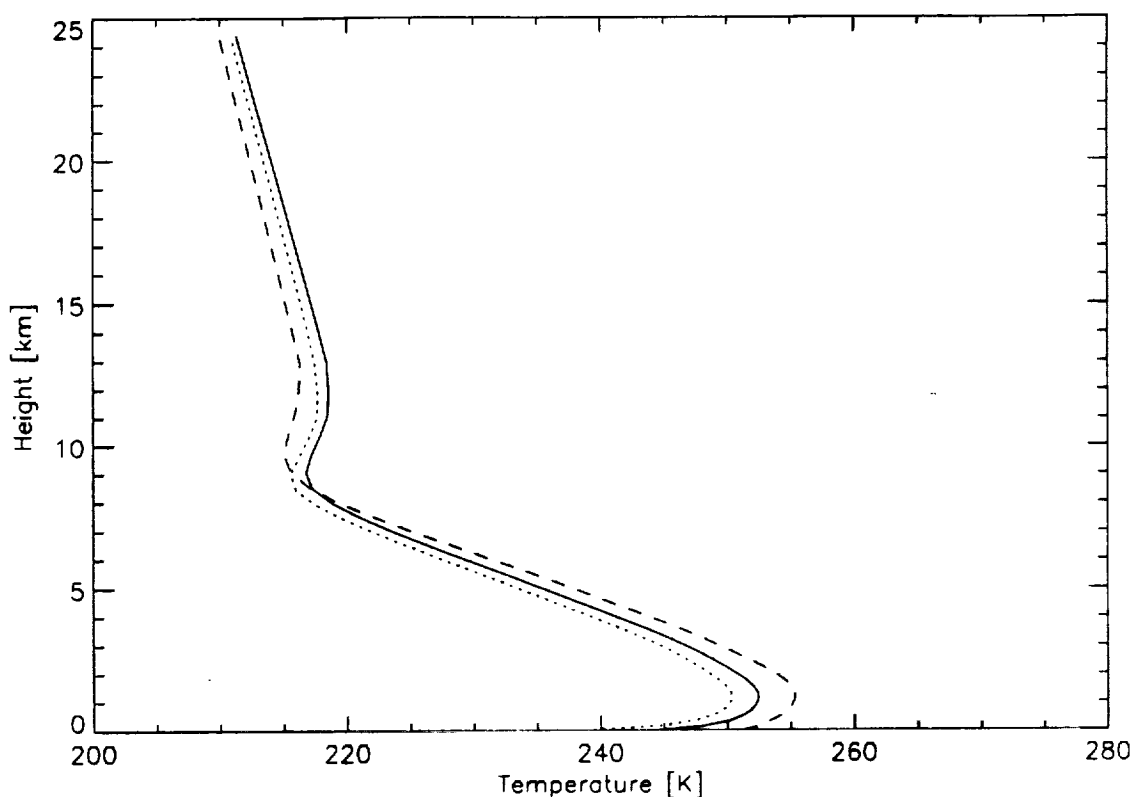


Fig. 6: Mean atmospheric temperature profile based on 350 radiosonde data sets from Soviet ice islands during two winters 1986 and 1987 (October to March).

Solid line: all profiles with cloud fractions 0 - 8.
 Dotted line: profiles with cloud fractions 0 - 2 (clear sky)
 Dashed line: profiles with cloud fractions 7 - 8 (cloudy sky)

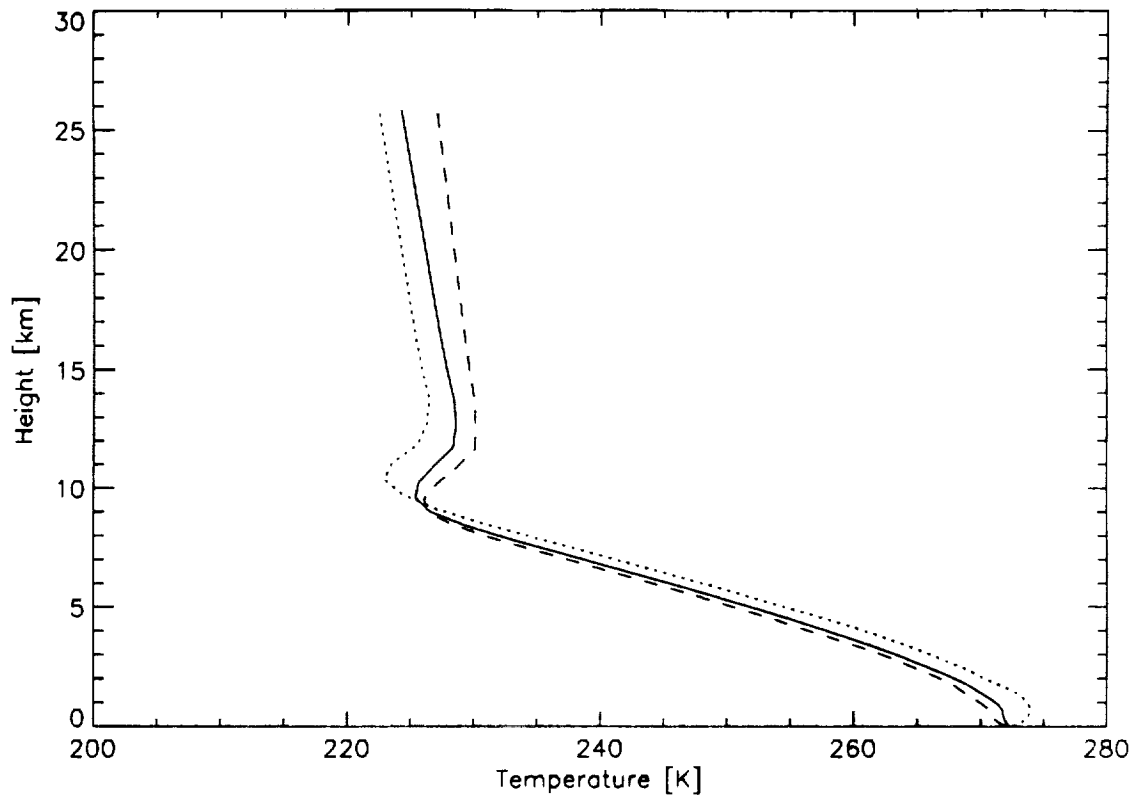


Fig. 7: Mean atmospheric temperature profile based on radiosonde data sets from Soviet ice islands during two summers 1986 and 1987 (June to August).

Solid line: all profiles with cloud fractions 0 - 8.
 Dotted line: profiles with cloud fractions 0 - 2 (clear sky)
 Dashed line: profiles with cloud fractions 7 - 8 (cloudy sky)

6. The Effect of Sensor Resolution on Derived Cloud Fraction

J. Key

An analytical description of the relationship between a satellite-derived geophysical parameter and sensor resolution is sorely needed. While there have been empirical studies of the effect of sensor resolution on parameter retrieval, they dealt only with cloud fraction (and a single cloud type such as cumulus) and cannot be generalized to other parameters. In our analytical approach to this problem, we are concerned only with the fraction of the image area covered by the geophysical parameter of interest; e.g., cloud fraction or open water fraction. It is assumed that subpixel area fraction cannot be determined but that "contamination" of the pixel can. Therefore, an indicator function is evaluated for each pixel, with a value of 1 if the original pixel value satisfies a given condition and 0 otherwise. The condition will, of course, be related to the fractional coverage within the pixel. The problem then becomes one of determining the probability distribution of the subpixel fractional coverage, which depends upon the pixel size and the spatial distribution of the geophysical parameter. This spatial distribution includes both size and shape characteristics, which are perhaps best described by an autocovariance function. Formalization of this problem is in progress, and will be detailed in the next report.

7. Arctic Radiation Flux Climatology

M. Haeffliger, K. Steffen, J. Key, A. Schweiger

Previous calculations were made using the radiative components reported in climatologies based on ice island, and station observations that in part rely on crude parameterization of radiative fluxes on surface observed cloud cover and surface temperature (Marshunova 1961). Since this early work a great deal of data that has potential for the computation of surface radiative fluxes has become available. For example, the International Cloud Climatology Project (ISCCP) has produced extensive data on cloud and surface parameters for several years in the Arctic. We have recently begun developing an Arctic radiation flux climatology based on the ISCCP monthly cloud product for the period 1 July 1983 through 31 December 1986. We will use these data to compute some of the radiative components in a surface energy balance climatology. Fig. 8 outlines the data flow including processing steps and sensitivity studies involved in computing radiative fluxes from the ISCCP data. The LOWTRAN-7 radiative transfer model will be used to estimate the surface fluxes based on cloud optical depth, surface temperature and reflectance, and atmospheric temperature profiles retrieved from TOVS (part of the ISCCP data set). Problems include the unknown cloud thickness, uncertain surface spectral signature in the shortwave portion of the spectrum, unknown cloud microphysical characteristics, and a lack of optical thickness estimates during the winter. Even with these problems, a useful product should result, and the problems identified in the process will help drive future research. This work will form an integral part of A. Schweiger's doctoral thesis, which deals with the Arctic surface energy balance.

In addition to the Soviet Ice Island data, radiosonde profile measurements obtained during the Swiss Greenland Expedition in 1990 were used for testing the radiative transfer model LOWTRAN-7 (Tab. 1). The data set includes 80 atmosphere profiles (pressure, temperature, humidity, wind), surface temperature and flux measurements.

Table 1: Comparison of measured and modelled longwave downwelling radiative flux at the Swiss expedition camp on the Greenland ice sheet (69° 17' N, 49° 17' W). The modelled values were obtained using radiosonde profile measurements and LOWTRAN 7 model.

Condition	Date	Measured (Wm ⁻²)	LOWTRAN-7 (Wm ⁻²)	Difference (%)
clear sky	6-17-90	216	205	-5.09
clear sky	7-1-90	228	225	-1.32
cloudy sky	7-23-90	309	301	-2.59
cloudy sky	7-26-90	283	282	-0.35

Comparisons with atmosphere profiles from the South Pole and Denver have shown, that calculated longwave fluxes for clear sky can be derived to an accuracy of $\pm 5\%$. Although preliminary results for cloudy sky seems very good, further analysis will be needed. Therefore, we intend to analyze the complete Greenland radiosonde data set (1990 and 1991) and derive comparative statistics with longwave radiation retrievals from satellite data under differing sky conditions.

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9. Submitted Papers

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